Sediment Quality in the San Juan Islands, Changes over a 10-Year Period

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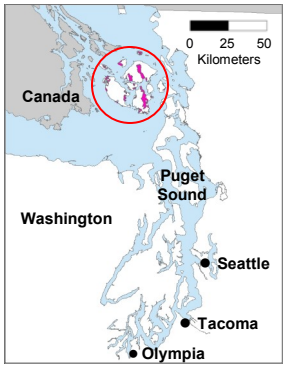
Findings

- Sediment quality did not change significantly from 2002-2003 to 2012.
- Overall sediment quality was high in 2012.
  - Exposure to chemical contaminants was *minimum* everywhere.
  - Most of the study area had no toxicity.
  - The Triad Index classified sediments as *unimpacted* or *likely unimpacted* almost everywhere.
- Bottom-dwelling organisms were *adversely affected* in almost 60% of the area, likely a function of the natural, physical environment.

In 2012, the Washington State Department of Ecology (Ecology) surveyed sediment conditions throughout the San Juan Islands and compared them to conditions from a similar survey in 2002-2003 as part of a Puget Sound status-and-trends monitoring program. The study area included the embayments within the archipelago (red circle in map at right). Surface sediments (top 2-3 cm) from 40 randomly selected locations were analyzed to determine:

- Concentrations of potentially toxic chemicals.
- Degree of response in laboratory tests of toxicity.
- Condition of sediment-dwelling invertebrates (benthos).



The sediment contaminant, toxicity, and benthic invertebrate data were rolled up into Ecology's Chemistry, Toxicity, Benthic, and combined Triad Indices.

Overall Results

None of the sediment quality indices changed significantly from 2002-2003 to 2012. Overall sediment quality, as measured by the Triad Index, statistically met the Puget Sound Partnership (PSP) target in 2012, an improvement from 2002-2003 (Figure 1).

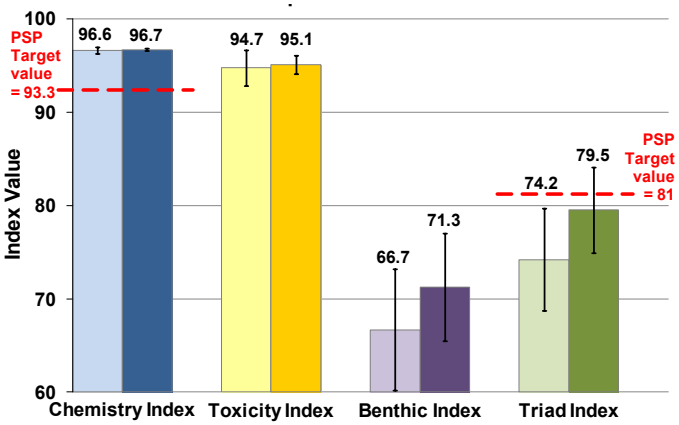


Figure 1. A comparison of weighted mean index values for the San Juan Islands in 2012 (dark bars) and 2002-2003 (light bars), with 95% confidence intervals. Also shown are the PSP target values for the Chemistry and Triad Indices (red dashed lines). Numerical values of the indices range from 0 (poor) to 100 (high quality).

Want more information?

This report covers only the primary results of the 2012 San Juans survey. Data and supporting information, including methods, are available on Ecology's website: **www.ecy.wa.gov/programs/eap/sediment.**

Sediment Monitoring of the San Juan Archipelago

Ecology sampled sediments throughout the San Juan Archipelago in June 2012 under the Puget Sound Ecosystem Monitoring Program (PSEMP). The region had been studied previously in 2002-2003 (Long et al., 2008), with the same field and laboratory methods. A new set of sampling stations was randomly selected for the 2012 survey. The survey design weights sample results by area. This enables Ecology to estimate the percent of area (spatial extent) with given sediment conditions and compare results from multiple surveys. Comparisons of spatial extent of sediment conditions follow Kincaid (2012). The study design, sampling and analytical methods, and list of parameters are described in Dutch et al. (2009, 2011) and on Ecology's website.

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Physical Conditions

The survey area consists of embayments within the archipelago. The inter-island channels and straits are too current-swept to have much soft sediment. Hence, all of the stations were shallow (<50 m depth), with most being <30 m deep. Sediments throughout the San Juan Islands were predominantly silt, sand, or mixed silt and sand. Clay content was generally less than 25% of the sediments by weight; gravel was usually <1%. One sample in outer Roche Harbor consisted of 28% gravel by weight. Total organic carbon (TOC) content of most of the sediment samples was less than 2% by weight. TOC averaged 1.4% and ranged up to 3.3%.

Chemical Contamination

Samples were analyzed for the concentrations of 135 toxic chemicals, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and other organic compounds. Metals and PAHs were almost always detected and measurable (96% of samples). The other target organic compounds (e.g., PCBs, pesticides) were detected in fewer than 6% of samples.

Concentrations of most individual chemicals remained unchanged from 2002-2003 to 2012. Cadmium and cholesterol concentrations decreased. Concentrations of chromium, two high-molecular-weight PAHs, and the majority of low-molecular-weight PAHs increased.

No chemical concentrations were found above (not meeting) the Washington State Sediment Cleanup Objective (SCO*) benthic chemical criteria (Ecology, 2013) at any of the sites. SCOs are sediment chemical concentrations below which no adverse biological effects to the benthic community are expected to occur. These criteria apply to the benthic community within the biologically active zone of surface sediment, typically the top 10 cm.

* formerly called Sediment Quality Standard (SQS)

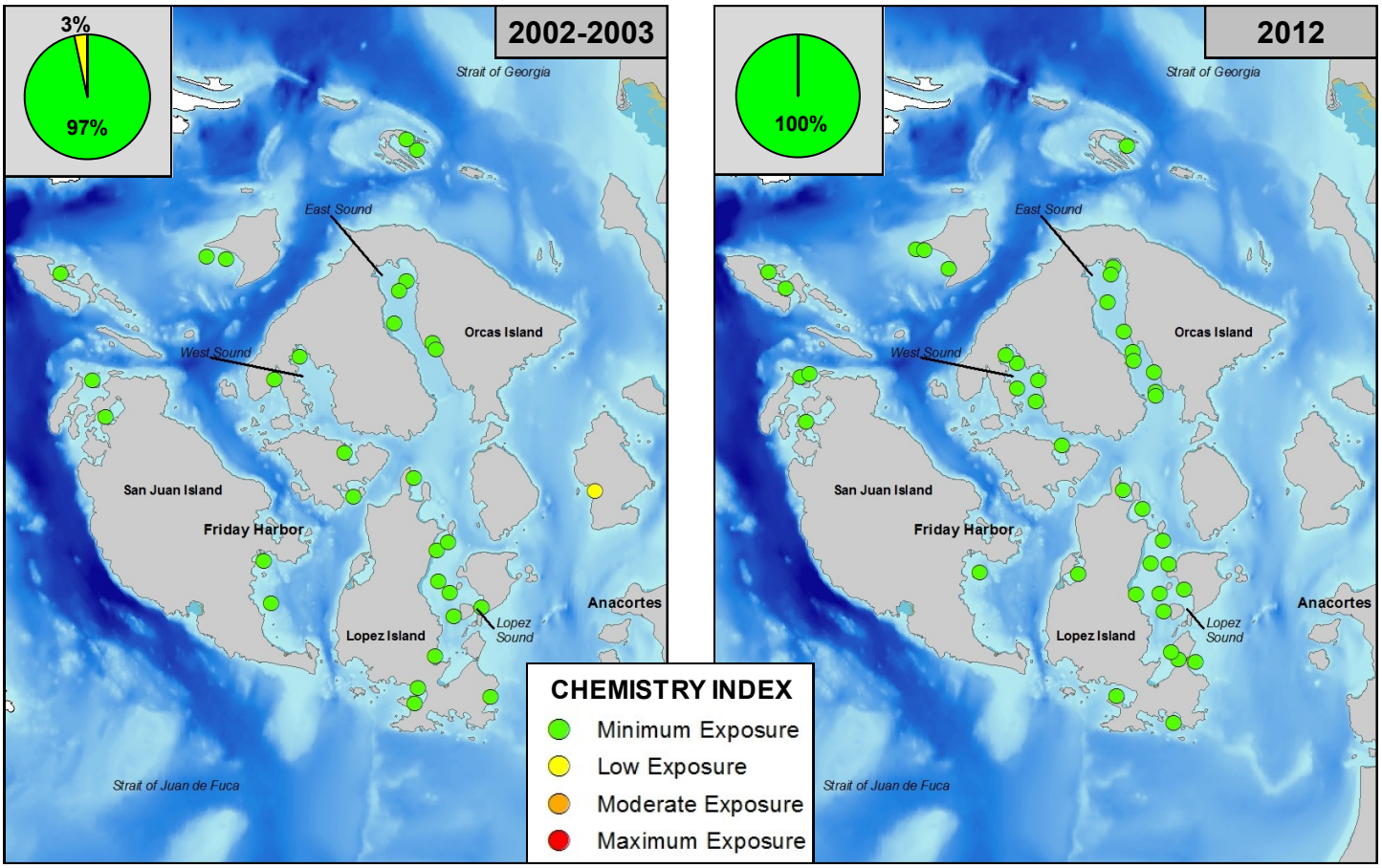

Figure 2. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Chemistry Index categories for the San Juan Archipelago in 2002-2003 and 2012.

Chemistry Index

Ecology's Chemistry Index (Long et al., 2013) is a multi-chemical index that accounts for the presence, concentrations, and potential toxicity of mixtures of chemicals. It is used to categorize sediments as having *minimum*, *low*, *moderate*, or *maximum* levels of exposure to the benthic community for chemicals which have defined SCO benthic chemical criteria (Ecology, 2013).

The Chemistry Index indicated that the entire (100%) study area had *minimum exposure* (Figure 2). The spatial extent of exposure to SCO-defined contaminants was not significantly changed from 2002-2003 to 2012.

Toxicity Index

Each sediment sample was analyzed with a 10-day amphipod survival test to gauge acute toxicity. The test involves exposing adult amphipods to sediments in the laboratory. Test results were used to generate Ecology's Toxicity Index (Dutch et al., 2014), which characterizes sediment toxicity into four categories, from *non-toxic* to *high toxicity* (Table 1).

The Toxicity Index indicated that 92% of the study area had *non-toxic* sediments. *Low toxicity* sediments were found in only 8% of the area (Figure 3). No sediments with *moderate* or *high toxicity* were found.

Table 1. Toxicity Index category descriptions.

Category	Description
Non-Toxic	Mean control-adjusted test results were not significantly lower than the controls **or** were ≥90% of controls
Low Toxicity	Mean control-adjusted test results were significantly lower than the controls **and** between <90-80% of controls
Moderate Toxicity	Mean control-adjusted test results were significantly lower than the controls **and** between <80-50% of controls
High Toxicity	Mean control-adjusted test results were significantly lower than the controls **and** <50% of controls

Regionwide, sediment toxicity was unchanged from 2002-2003 to 2012 (Figure 3).

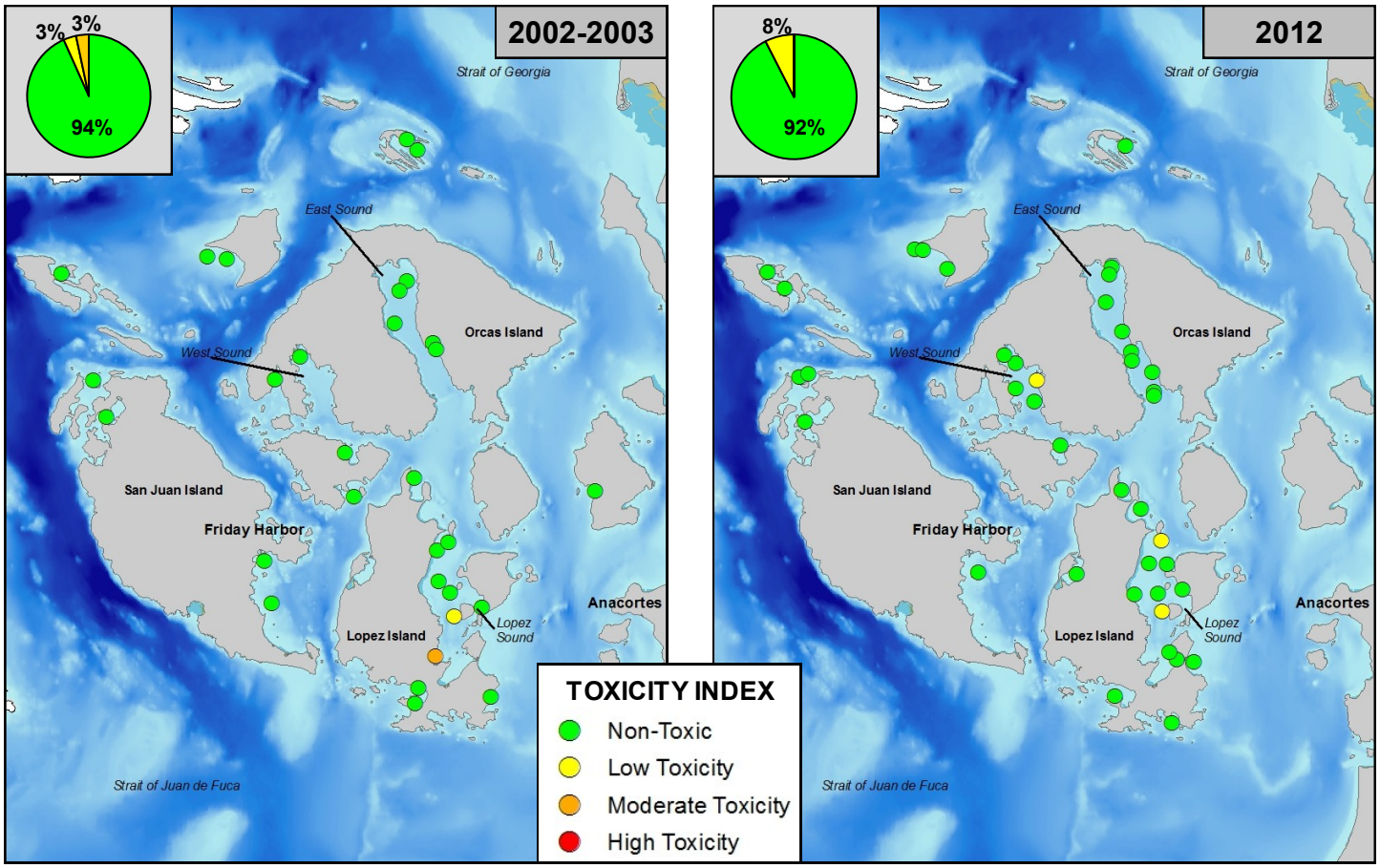

Figure 3. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Toxicity Index categories for the San Juan Archipelago in 2002-2003 and 2012.

Benthic Invertebrates

Benthic invertebrate organisms (benthos) were identified and counted for all locations sampled in 2012. Multiple community measures were calculated from the species and count data to characterize benthic invertebrate abundance and diversity. All of the abundance and diversity measures were the same overall in 2012 as ten years earlier; however, the highest abundance values for most major taxonomic groups except polychaetes (marine worms) were somewhat lower in 2012 than in 2002-2003.

Polychaetes were the most abundant organisms at almost all of the stations, generally accounting for >40% of the animals in each sample. Molluscs were next most abundant overall, often 20-50% of the total abundance, though molluscs were absent at one station in East Sound. Arthropods were the most abundant organism at one station in Fisherman Bay (Lopez Island). Echinoderms and other types of marine organisms were found infrequently or in low numbers.

Benthic Index

Ecology's Benthic Index is a determination of whether the invertebrate assemblages appear to be *adversely affected* or *unaffected* by natural and/or human-caused stressors. The determination is made by benthic experts based on a suite of calculated indices, including total abundance, major taxa abundances, taxa richness, evenness, and species dominance, compared to median values for all of Puget Sound. Abundances of stress-sensitive and stress-tolerant species at each station are also considered.

The benthic assemblages from the 2012 San Juan Islands survey were judged to be *adversely affected* in 23 of the 40 samples, representing 58% of the area of the region (Figure 4). The spatial extent of *adversely affected* benthos was statistically unchanged from 2002-2003 to 2012.

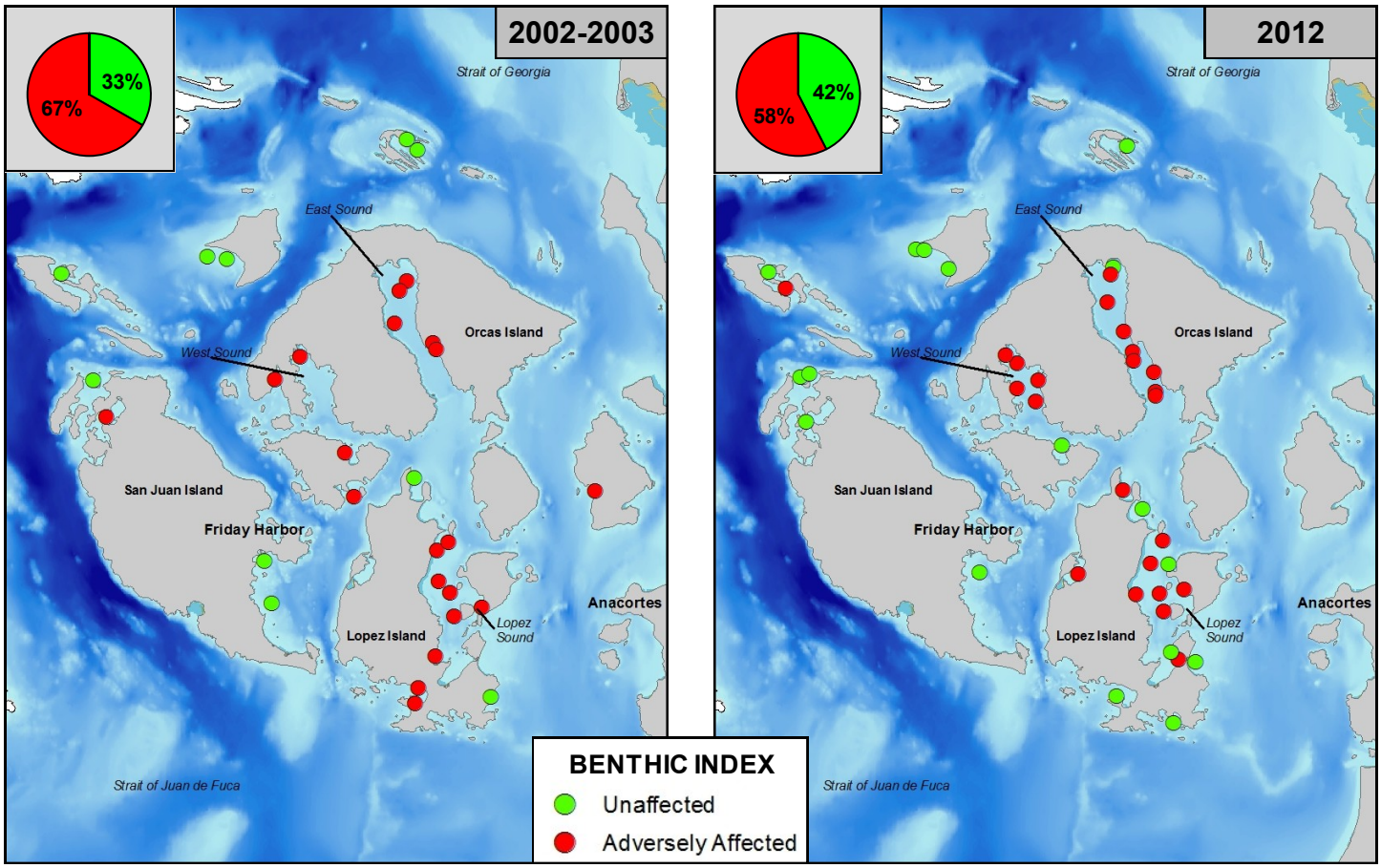

Figure 4. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Benthic Index categories in the San Juan Archipelago in 2002-2003 and 2012.

The *adversely affected* condition is an indication that the community is not very diverse or abundant or is dominated by stress-tolerant animals. It is not possible with this type of survey to determine causes or to distinguish between natural and human-caused stresses. In this case, however, given the physical environment in the San Juan archipelago, some of the benthic invertebrate communities designated as *adversely affected* probably were affected by natural conditions. *Adversely affected* benthos occurred in the same areas in 2002-2003, likely also due to natural environmental stresses.

Triad Index

Ecology's Triad Index combines evidence from the triad of measures (chemistry, toxicity, benthos) to classify sediment quality into six categories of impact by chemical contamination and/or other environmental stressors (Dutch et al., 2014). Categories range from *unimpacted* to *clearly impacted*, and *inconclusive* when lines of evidence are conflicting. This multiple-lines-of-evidence approach was adapted from methods developed for the state of California to classify sediment quality (Bay and Weisberg, 2012).

Table 2. Specific combinations of index results (chemistry, toxicity, benthic) that led to Triad Index categories for the San Juan Archipelago in 2012. Spatial extent (percent of study area) is given for each combination.

Chemistry Index	+ Toxicity Index	+ Benthic Index	= Triad Index	% of Area
Minimum exposure	Non-Toxic	Unaffected	Unimpacted	42.5%
		Adversely affected	Likely unimpacted	50.0%
	Low		Inconclusive	7.5%

In 2012, 92.5% of the area had *unimpacted* sediments, with *minimum* contamination and no toxicity (Table 2; Figure 5). The remaining 7.5% was classified as *inconclusive*, with conflicting Chemistry, Toxicity, and Benthic Index results. None of the study area in 2012 was classified as *possibly*, *likely*, or *clearly impacted*.

The 2012 Triad Index category spatial extents were similar to those in 2002-2003.

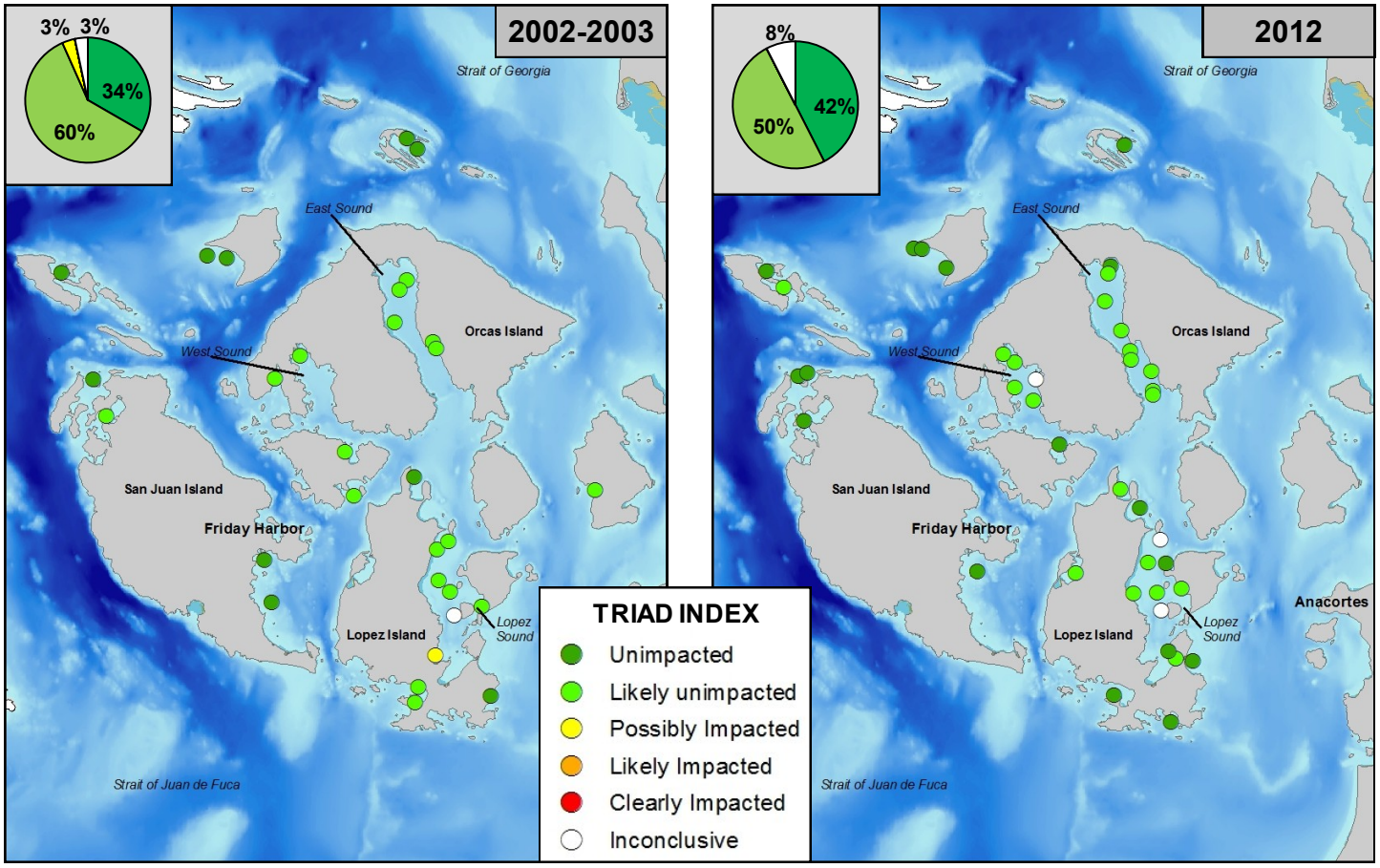

Figure 5. Spatial patterns at sampling stations and estimated spatial extent (percent of area, shown in pie chart) for the Triad Index results in the San Juan Archipelago in 2002-2003 and 2012.

The San Juan Archipelago Compared to All of Puget Sound

Comparison of the 2012 San Juan Islands Triad Index results to those for 2002-2003 (Kincaid, 2012 method, α=0.05) shows no significant changes in sediment quality (Figure 6). The San Juan Islands had significantly less *unimpacted* area and significantly more *likely unimpacted* results than the 1997-2003 Puget Sound baseline. (Updated 2004-2014 Puget Sound baseline not yet available.)

The *adversely affected* condition of the benthos was the primary factor influencing the extents of the Triad Index categories for the San Juan Islands in both 2002-2003 and 2012. As stated earlier, the *adversely affected* benthos likely reflected the natural physical conditions.

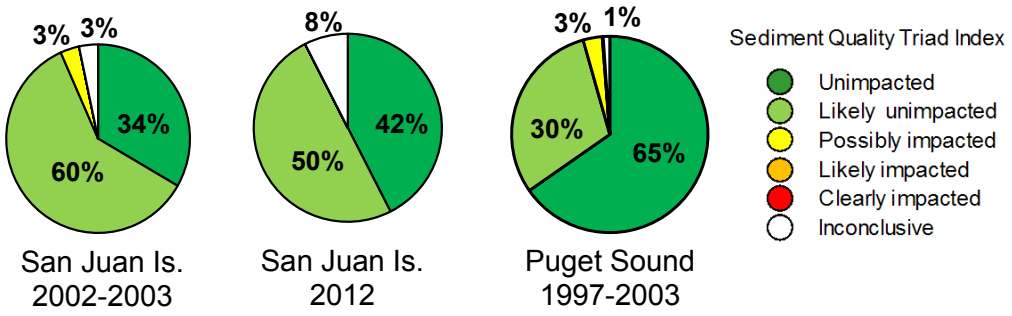

Figure 6. Spatial extent (percent of area) for the Triad Index categories for the San Juan Archipelago in 2012 (from Figure 5), compared to 2002-2003 and to the Puget Sound 1997-2003 baseline. Proportions smaller than 1% are not shown.

The Chemistry Index and the Triad Index as "Vital Signs" Indicators for the Puget Sound Partnership

Ecology's Chemistry and Triad Indices, and also the percent of chemicals exceeding (not meeting) the Washington State Sediment Cleanup Objective (SCO) benthic chemical criteria (Ecology, 2013), were adopted by the Puget Sound Partnership (PSP) to serve as "Vital Signs" indicators of the condition of Puget Sound (www.psp.wa. gov/vitalsigns/index.php). Weighted mean Chemistry and Triad Index values are compared with target values for highest quality, adopted by the PSP.

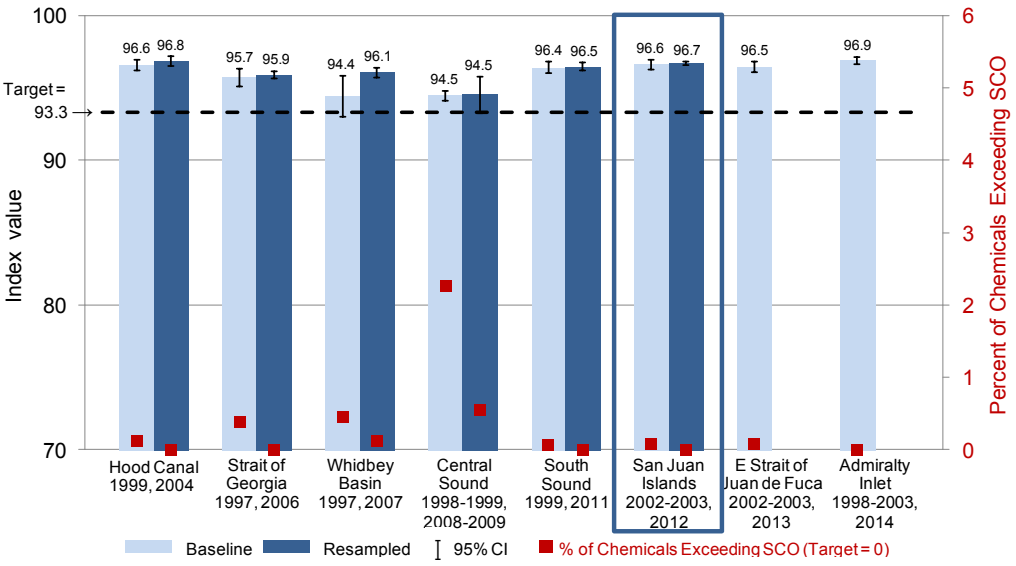

Figure 7. Change over time in Chemistry Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. The PSP's 2020 target value of 93.3 is shown as a dashed black line. Red squares illustrate the percentages of chemicals with concentrations exceeding (not meeting) SCO criteria.

The indices also are compared between years of repeated sampling to determine changes over time and among regions.

The Chemistry Index value for the San Juan Islands was unchanged from 2002-2003 to 2012 and was above the target value of 93.3 (Figure 7). The San Juan Islands region was similar to several other regions of Puget Sound, though it had a higher Chemistry Index value than the Strait of Georgia, Whidbey Basin, and Central Sound regions, indicating lower exposure to contaminants.

The percent of chemicals in the San Juan Islands exceeding SCO benthic chemical criteria met the PSP target of zero in 2012 (Figure 7).

The Triad Index value in 2012 was statistically unchanged from that in 2002-2003; however, the confidence interval for the mean in 2012 covered the PSP target value of 81, indicating that the target was met (Figure 8). The PSP target value corresponds to the minimum value in the *unimpacted* Triad category.

Overall sediment quality in the San Juan Islands region in 2012, as indicated by the Triad Index, was similar to that in the Strait of Georgia, Whidbey Basin, and South Sound regions. The Triad Index value was lower in the San Juan Islands than in the Central Sound region, which had a lower percentage of *adversely affected* benthos, but higher than in the Hood Canal region (2004), which had greater exposure to contaminants and toxicity.

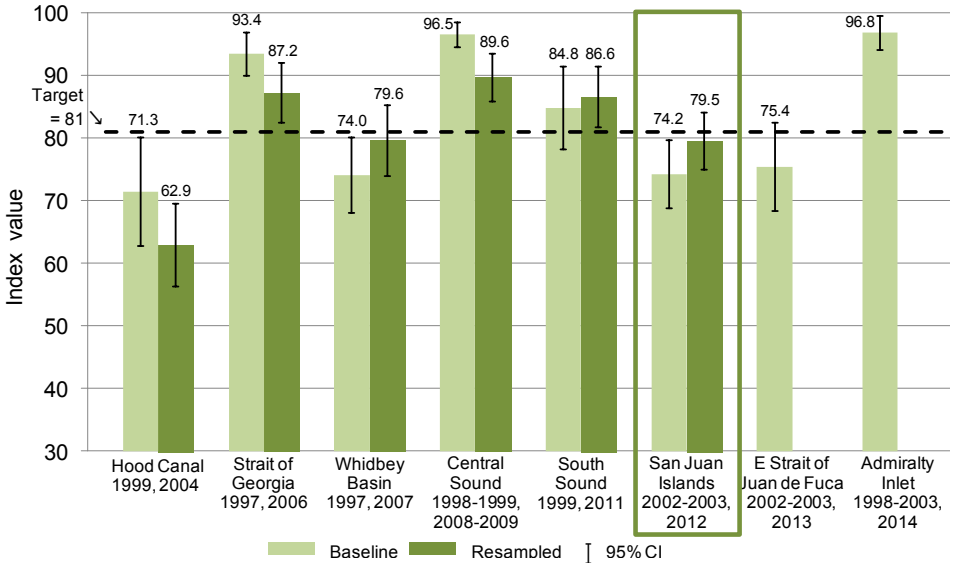

Figure 8. Change over time in Triad Index values for eight geographical regions of Puget Sound. Weighted means from baseline (lighter bars) and resample (darker bars) surveys are displayed with 95% confidence intervals. Also shown is the PSP's 2020 target value of 81 (dashed black line).

Summary, Conclusions, Future Directions

Sediment quality in the San Juan Archipelago in 2012 was *unimpacted* or *likely unimpacted* almost everywhere. Exposure to chemical contaminants was *minimum*, and sediments were almost always *non-toxic*. Benthic invertebrate community condition, however, was *adversely affected* in almost 60% of the region, resulting in the classification of sediment quality in those areas as *likely unimpacted* or *inconclusive* (conflicting conditions).

Although it is not possible to state why the benthos were *adversely affected*, given the physical environment in the San Juan Islands, the situation is probably not due to anthropogenic (human-caused) conditions that could be improved by management action.

Ecology's Marine Sediment Monitoring Program is working to develop a more sensitive indicator of benthic condition that would enable categorizing benthic communities more finely than the current Benthic Index's binary designations.

The current Chemistry Index used for characterization of exposure of benthic organisms to chemical contaminants was developed for the heavy metals and industrial chemicals which were the primary pollutants identified in estuaries in the 1970s and 1980s. Such chemical contaminants have been the focus of cleanup actions and source control by multiple agencies over the past several decades. However, there are many more chemicals entering Puget Sound and surrounding waters, many of which are associated with human population growth and settlement rather than industrial output; i.e., non-point vs. point sources. We are currently revising the list of chemical contaminants for future sediment monitoring.

In addition, there are many more effects of unhealthy sediment conditions on animals than measured by the long-used amphipod survival toxicity test. We are exploring newer technologies in toxicity tests that can give reliable indications of other types of harm (such as reduced reproduction) to benthic organisms.

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[1] Now called the Puget Sound Ecosystem Monitoring Program.

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